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DEPTH DISCRIMINATION AS A FUNCTION OF TARGET AND BACKGROUND CHROMATIC COMPOSITION

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Many monochromatic display devices are being used and are planned for future use. This study was designed to explore the effect on visual performance of a narrow wavelength stimulus environment. The results suggest that for a neutrally adapted eye, depth discrimination of colored targets are at least as easily made as those for achromatic targets and in general more easily made than when the eye is adapted to chromatic stimulus. It is also suggested that when the eye is adapted to a low intensity neutral level, depth discrimination errors are smaller for all of the wavelengths used at or near an optical infinity distance except 5800 Angstroms.

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INTRODUCTION

Accommodation and depth perception are important performance parameters for flight personnel. Two examples of perceptual failure where incorrect accommodation is felt to play a major contributing role are "empty field myopia" and "night myopia." In both of these cases, targets which are located at significant distances from the observer are not detected although the visual angles subtended by the targets are clearly above threshold values and should be easily visible. The assumption has been that the accommodative state of the observer's eye is such that the targets are not imaged sharply on the retina, and that the blurred image is not detected as the observer searches a visual field which is devoid of other stimuli to promote an infinity accommodation state of the eyes. Depth perception of both near and far targets is important for flight personnel because of visual performance requirements both inside and outside the cockpit.

A great deal of theoretical and experimental effort has been directed toward developing a basic understanding of accommodation and depth perception. The quality of the retinal image has been demonstrated to play a central role in both responses. Fincham (1) and Campbell and Westheimer (2) demonstrated the role of blurring of the retinal image as a stimulus for accommodation. Under laboratory conditions in which stereopsis and other cues to depth such as texture and size were eliminated, the accommodation response was immediate and correct in achromatic lighting conditions when a target was defocussed. It is interesting to note that the accommodation response did not occur when the target was blurred, but no defocussing occurred. The immediate and correct response to defocussing was lost by many observers when operating in a monochromatic light environment. Some observers were able to respond appropriately with practice (2) while others were unable to do so (1).

The monochromatic effect on the accommodation response, a response which is important in depth perception, raises questions regarding the ability of aircrew personnel to respond appropriately in a monochromatic light environment. Many types of display devices which are in use, are under active development, or are anticipated in the near future, make use of image generating devices such as cathode ray tubes with monochromatic phosphors or light emitting diodes and lasers which are monochromatic devices The study reported here was conceived as one of a series of studies designed to explore the effect on visual performance of a narrow wavelength stimulus environment. Observers were required to adjust targets in the depth dimension under white light and narrow band wavelength conditions in order to determine whether any changes in performance were associated with the chromatic character of the visual field.

METHODS AND MATERIALS

APPARATUS

A diagram of the optical system used to present the visual stimuli is shown in figure 1. The light sources in the two beams of the optical system are tungsten filament lamps at T_1 and T_2. The light beams pass through collecting lenses at L_1 and L_7, collimating lenses at L_2 and L_8, interference and neutral density filters at F_1 and F_2 and are brought to a focus by L_3 and L_9 at the apertures A_1 and A_3. The beams are again collimated by lenses L_4 and L_{10}. Targets are located in the collimated portions of the beams at X_1 and X_2. The beams are again focused by L_5 and L_{11} at apertures A_2 and A_4, collimated by lenses L_6 and L_{12} which image X_1 and X_2 at I between the beam-splitter, B, and the ocular of the system, E. E is mounted in the wall of the light tight chamber in which the observer is located. To the eye of an observer positioned at EP by a dental impression bite plate, the last lens of the ocular is seen in Maxwelliam view as an evenly illuminated 60° field when no field stop is placed in the collimated portion of the beam. The mirror, M, and beam splitter, B, direct and combine the two beams to present a single visual field to the observer, O, positioned at EP.

The targets at X_1 and X_2 are positioned so that they are located side by side in the 60° field presented to the O and separated by 1° at the closest points. The targets are Xs which are 1.8° in the horizontal dimension and 2.25° in the vertical dimension. In the phase I experiment the targets are opaque Xs on a light background. In phase II the targets are clear Xs on a dark background. Neutral density and interference filters located at F_1 and F_2 permit five chromatic and one achromatic stimulus conditions to be used. The peak transmittances of the interference filters are 4600Å, 5000Å, 5400Å, 5800Å, and 6200Å. The spectral bands are 10 Angstroms at one-half peak amplitude.

The stimulus sequencing, and data recording are controlled automatically by a programmable digital logic system. The control apparatus is shown in schematic diagram in figure 2. The observer's controls consists of response switches, R, and a foot switch, FS. The response switches permit the O to control the motor which adjusts the depth position of the target in beam 2 of the optical system. The foot switch is operated by O to signal that the depth adjustment is complete, and thereby end an experimental sequence. The electro-mechanical controls consist of shutters, S_1 and S_2, which effect the presentation of the targets, target positioning motors, T_1 and T_2, which adjust the depth position of the targets, and filter positioning motors, P_1 and P_2, which control the adjustment of the target chromatic composition. A timer, C, provides a measure of the Os response time. The digital logic system sequences the operation of all of the electro-mechanical devices except T_1 and T_2 and mediates the inputs to the data recording portion of the apparatus. The data recording device is a paper tape printer which permits printing of the experimental sequence number, response time, filter conditions, and the depth position of the targets. Both of the targets (T_1 and T_2) could be adjusted in depth by the experimenter, E. The T_2 target is adjusted by the O.

CALIBRATION

The radiances of the unfiltered visual field presented by each beam were measured with a EG&G model 580/585 spectroradiometer, and the luminances were calculated. The transmittances of the interference filters were measured on a Perkin-Elmer model 402 UV-Visible spectrophotometer. The maximum luminances of the filtered fields were calculated. The neutral density required to adjust the luminance of each of the chromatic fields and the achromatic field to that of the dimmest field produced by an interference filter was then calculated. The filter combinations determined in this way were placed in the apparatus and the accuracy of the calculated photometric matches were verified and any minor adjustments made by means of a psychophysical procedure. The adjustments eliminated just detectable differences between beams and between filter conditions in a beam. The adjustments required were all on the order of 0.01 ND or less.

The depth, vertical and horizontal calibrations were accomplished by mounting a calibrated telescope in front of the ocular of the optical system. The depth measurements were made by adjusting the telescope for focus at distances from 10 centimeters to 30 meters. The targets were adjusted until they were in focus at each of the distances and the readings were taken from counters which indicate the position of the targets in the system. Target position settings, as indicated on the counters, could then be translated into depth in meters. The horizontal and vertical calibrations in visual angle were made by rotating the telescope around the focal point of the ocular and reading the scale of the mount which was calibrated to 15" of arc. The cross hairs of the telescope were set at the end of the stimulus to be measured, the setting of the telescope mount scale was noted. The mount was then rotated so that the telescope cross hairs intersected the other end of the stimulus dimension being measured and the scale setting was noted again. The difference between the two readings provided a measure of the visual angle of the stimulus dimension under examination.

PROCEDURE

The experimental design is shown in table I. As the matrix in table I shows, six filter conditions and eight depth conditions were investigated for each of the two phases. The order of presentation of the filters to each O, and the order of presentation of depths for each filter condition were determined by a random selection procedure.

Prior to the start of each experimental session, the E set the standard target, X_1, to the required depth. The comparison target, X_2, was set to a depth which was displaced from that which equaled the comparison target depth. The direction and distance of the displacement were selected on a random basis. The O was then seated in the light tight enclosure and permitted to dark adapt for 15 minutes. At the end of the 15 minute interval, a buzzer sounded to alert the O to get into position at the ocular of the optical system. Five seconds after the O was signalled to get into position, the shutters at S_1 and S_2 opened and the two targets were presented to the O. Using the response switches, R, the O adjusted the comparison target, X_2, depth setting until it appeared equal to the standard target, X_1. When the O was satisfied with the match, the foot switch was pressed which closed the shutter and started the time for the next sequence, stopped the elapsed time clock and printed the elapsed time, the filter wheel positions, the X_2 depth setting, and the sequence number. After a one minute readaptation period, the buzzer sounded to alert the O and the sequence was repeated. After five sequences the E changed the filter wheel positions and the X_1 depth setting as required for the next condition and the sequences were repeated. Each experimental session lasted approximately one and one half hours which avoided observer fatigue and permitted data to be collected for five to six conditions during a session. Full data were collected for two observers in both phase I and phase II.

RESULTS

The average error in meters of the settings by the observers is shown in table II and are plotted in figure(s) 3 through 8. A general examination of table II suggests that the adjustment errors tend to be greater in phase II, a colored target on a black background, than in phase I, a black target on a colored background. An Analysis of Variance was performed on the data. The Analysis of Variance Summary Table is shown in table III. Neither of the variances produced by the distance of the targets nor the color of the targets was significant. The variances produced by the experimental phases as a primary effect and in interactions with the other conditions were significant. Because of the significant interactions, the significances of the differences between individual pairs of means were computed.

The observed frequencies of significant and nonsignificant mean differences for within phase and between phase comparisons are shown in the chi square (X^2) contingency table, table IV. The total number of within phase comparisons was 2,256 of which 1,790 were significant and 466 were not. The total number of between phase comparisons was 2,304 of which 2,051 were significant while only 253 were not. The X^2 which was computed to determine whether the obtained frequencies differed significantly from the expected frequency distribution of significant differences indicates that the number of conditions in one phase in which the magnitude of the error in depth setting was significantly different from a condition in the other phase was greater than the number which differed significantly from a condition in the same phase. The qualitative observation that the magnitude of the errors in phase II is greater than that for phase I is, therefore, supported by the X^2 evaluation.

DISCUSSION

The results of the experiment reported here suggest two things with respect to the use of colors in displays and in lighting systems. In phase I of the experiment, the adaptation of the observer was neutral, and at a low level of intensity, and the targets which were discriminated were very narrow spectral band targets. In phase II the observer was adapted to the narrow spectral band and the targets which were discriminated were neutral, high contrast targets. The results suggest that for a neutrally adapted eye, depth discriminations of colored targets are at least as easily made as those for achromatic targets, and in general more easily made than when the eye is adapted to chromatic stimulis. In addition, the results also suggest that when the eye is adapted to a low intensity neutral level, depth discrimination errors are smaller for all of the wavelengths used at or near an optical infinity distance except 5800 Angstroms. The errors at 5800 Angstroms were greater at 8 meters than they were at any of the shorter distances. By comparison, in phase II, where the eye was adapted to the experimental wavelengths, the performance in the 5800 Angstrom condition is among the most accurate at all distances, and the error trend at the longer distances is decreasing rather than increasing as was the case in phase I.

One acuity level was used to evaluate the depth discrimination performance under the different spectral conditions in the study reported here. Of concern also is the effect of spectral conditions on acuity discriminations. The next study in this series is planned to provide further insight into the relationship between relatively spectrally pure stimuli and visual performance by examining the acuity discrimination responses under the different spectral conditions.

TABLE I

EXPERIMENTAL DESIGN

Phase I

Filter λ Å	Distance (M) 1	2	3	4	5	6	7	8
4600	A	B	C	D	E	F	G	H
5000	I	J	K	L	M	N	O	P
5400	Q	R	S	T	U	V	W	X
5800	Y	Z	AA	BB	CC	DD	EE	FF
6200	GG	HH	II	JJ	KK	LL	MM	NN
Achromatic	OO	PP	QQ	RR	SS	TT	UU	VV

Phase II

4600	A'	B'	C'	D'	E'	F'	G'	H'
5000	I'	J'	K'	L'	M'	N'	O'	P'
5400	Q'	R'	S'	T'	U'	V'	W'	X'
5800	Y'	Z'	AA'	BB'	CC'	DD'	EE'	FF'
6200	GG'	HH'	II'	JJ'	KK'	LL'	MM'	NN'
Achromatic	OO'	PP'	QQ'	RR'	SS'	TT'	UU'	VV'

TABLE II

Average Error in Meters

Distance (M)

Phase I (Opaque Target)

Filter λ Å	1	2	3	4	5	6	7	8
4600	1.68	1.84	2.58	1.48	4.83	0.86	1.92	3.37
5000	2.82	0.69	3.62	4.79	5.82	2.13	1.42	3.06
5400	0.95	5.86	3.75	2.27	3.22	1.55	1.07	1.78
5800	5.20	2.55	6.17	1.76	3.94	2.76	3.55	7.58
6200	2.75	0.82	1.10	3.20	2.82	5.33	5.69	1.79
Achromatic	2.23	4.52	5.12	8.18	2.73	1.59	1.25	3.68
Phase II (Clear Target)								
4600	6.24	4.98	4.61	5.03	7.44	6.55	7.10	2.27
5000	5.63	2.85	1.87	3.72	6.63	4.08	5.12	8.04
5400	5.86	6.52	6.35	5.49	7.33	8.47	7.76	6.80
5800	4.62	5.59	2.18	7.29	5.69	6.52	5.65	4.58
6200	4.72	2.29	4.91	6.59	2.69	4.88	7.73	7.06
Achromatic	7.51	6.56	4.14	3.60	7.45	7.10	4.75	5.58

TABLE III

ANALYSIS OF VARIANCE

Summary Table

Source	df	F
Distance (D)	7	1.22
Filters (F)	5	1.73
Phases (P)	1	84.20***
FxD	35	1.59*
PxD	7	2.56**
PxF	5	3.07**
FxPxD	35	1.92**
Error	864	
Total	959	

*P .05

**P .01

***P .001

TABLE IV

Frequencies of Mean Difference Significances

Level of Significance	Within Phase Comparison		Between Phase Comparison	
	Obs.	Exp.	Obs.	Exp.
0.01	1652	1792.93	1972	1831.07
0.05	138	107.36	79	109.64
not significant	466	355.72	253	363.28
Σ	2256		2304	

$X^2 = 106.91$

$df = 2$

$P < 0.001$

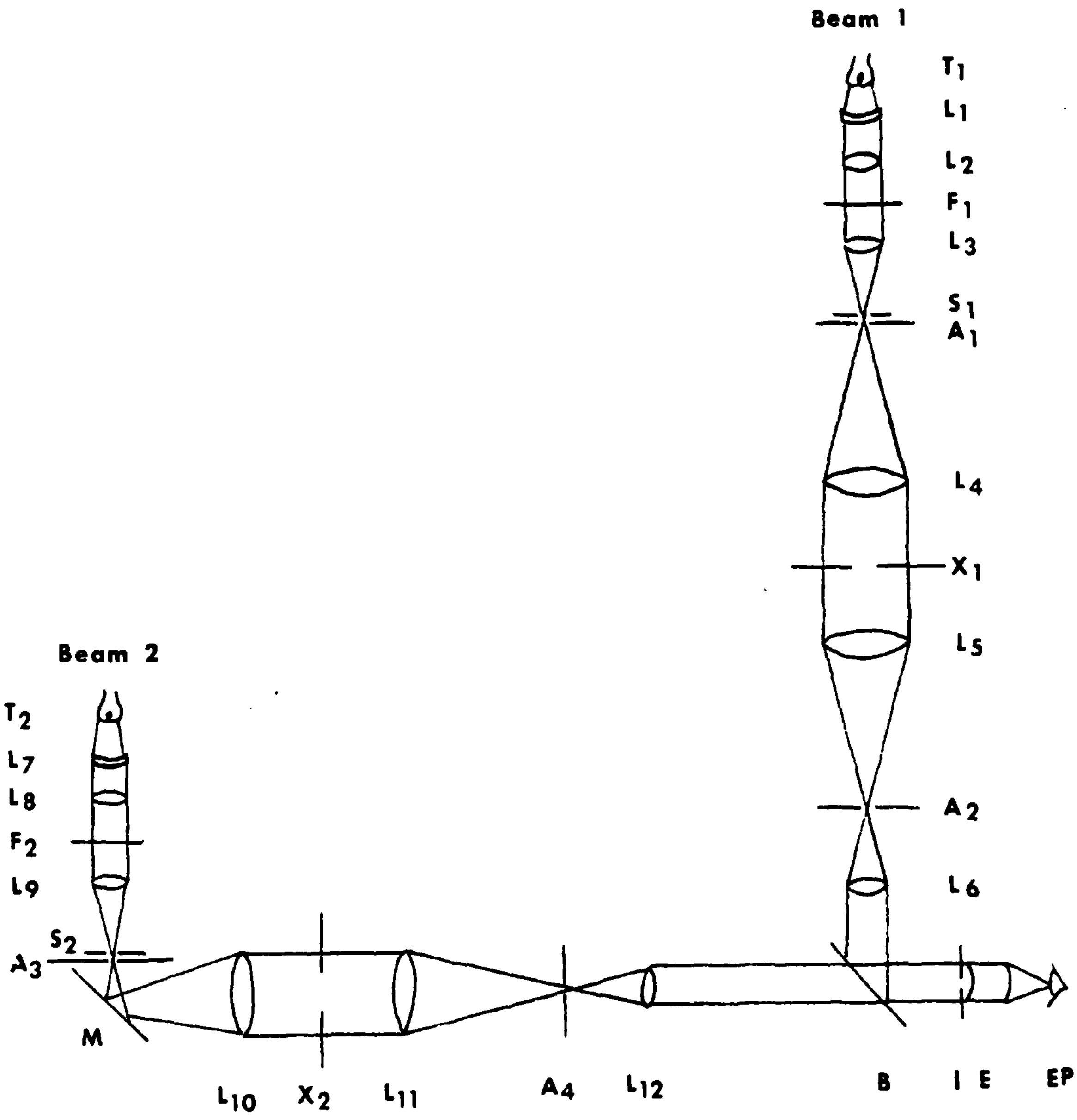

Figure 1 - Optical System Diagram

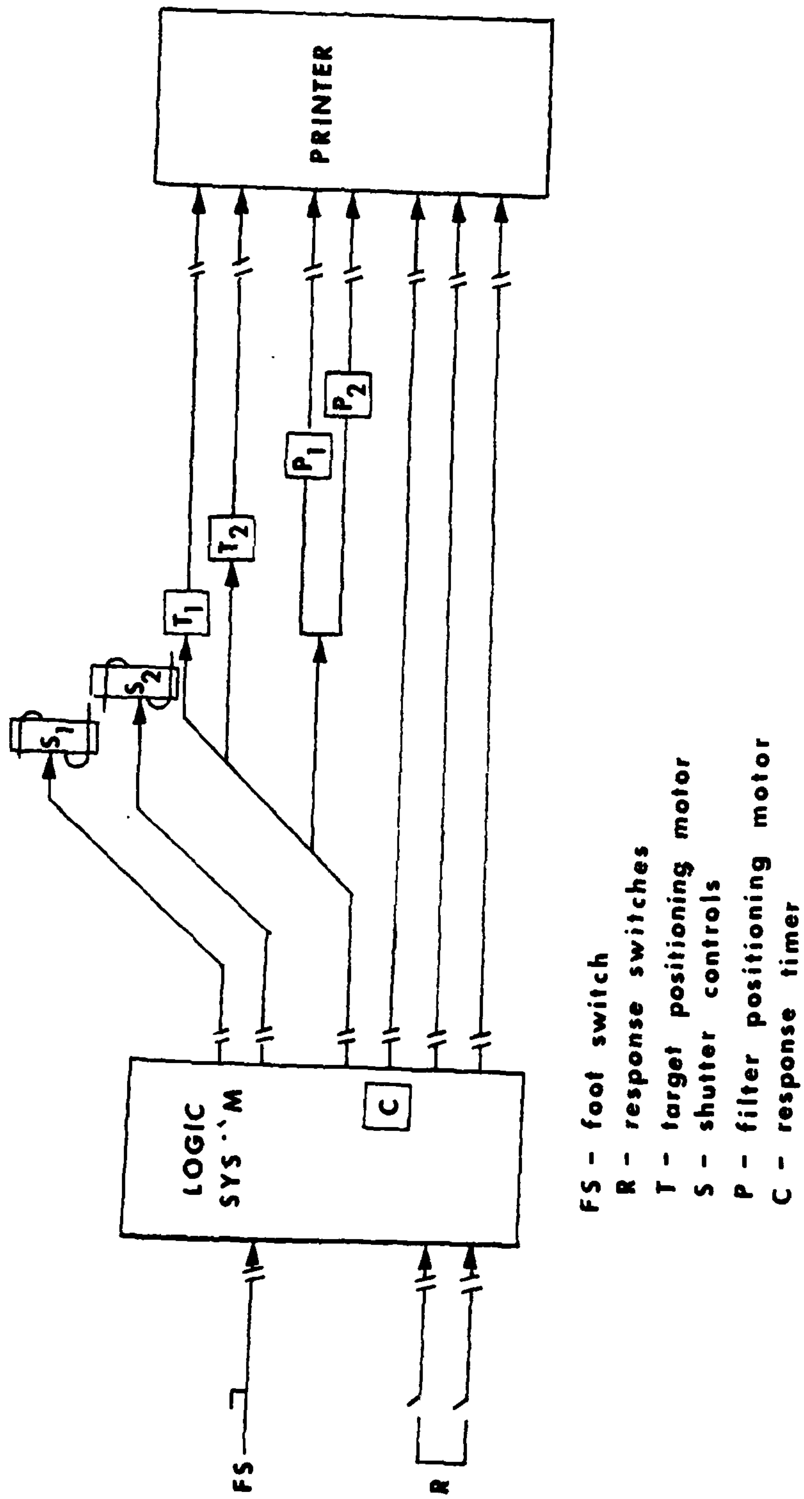

Figure 2 - Stimulus Control System Schematic Diagram

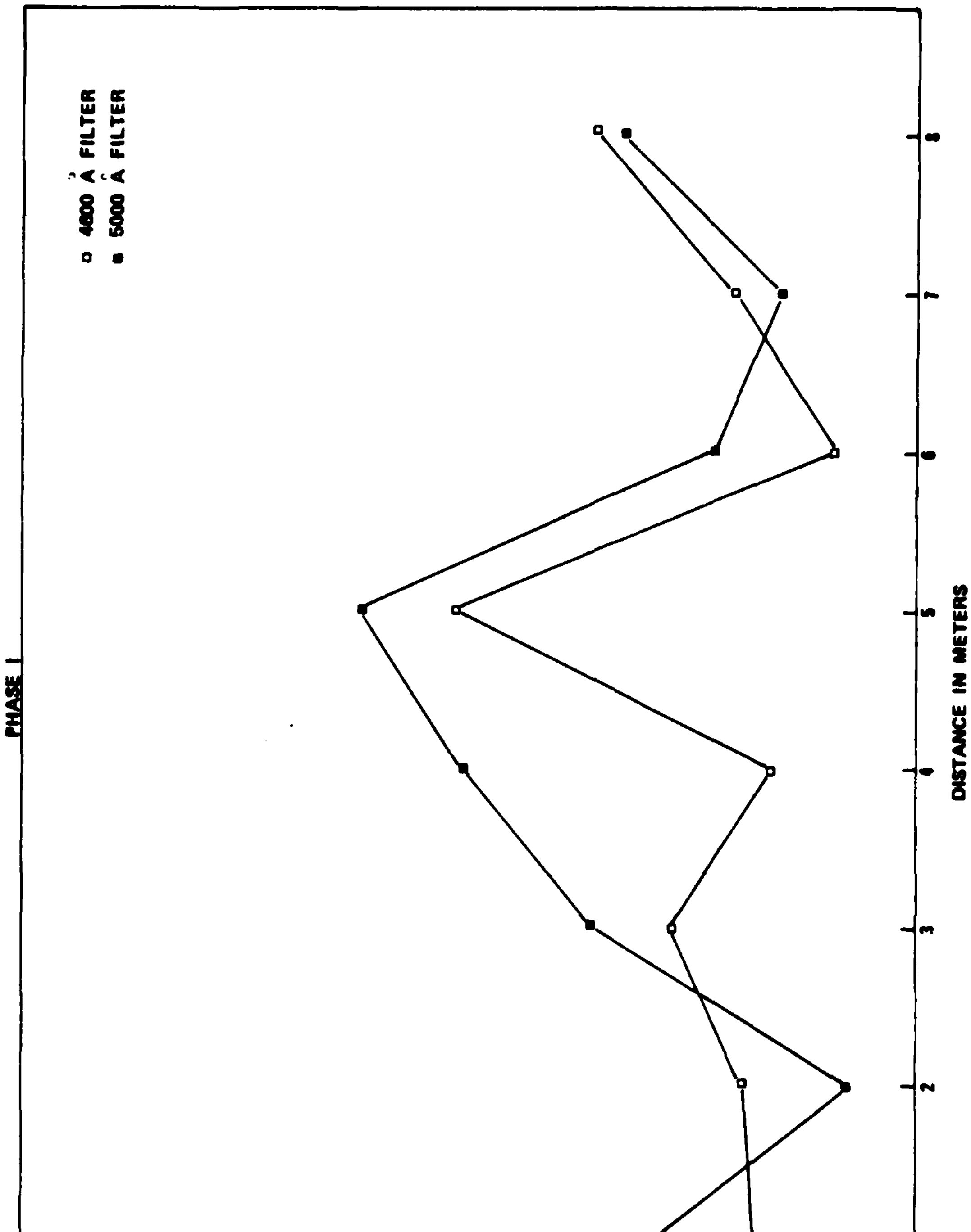

Figure 3 - Phase I-4600 Å Filter, 5000 Å filter

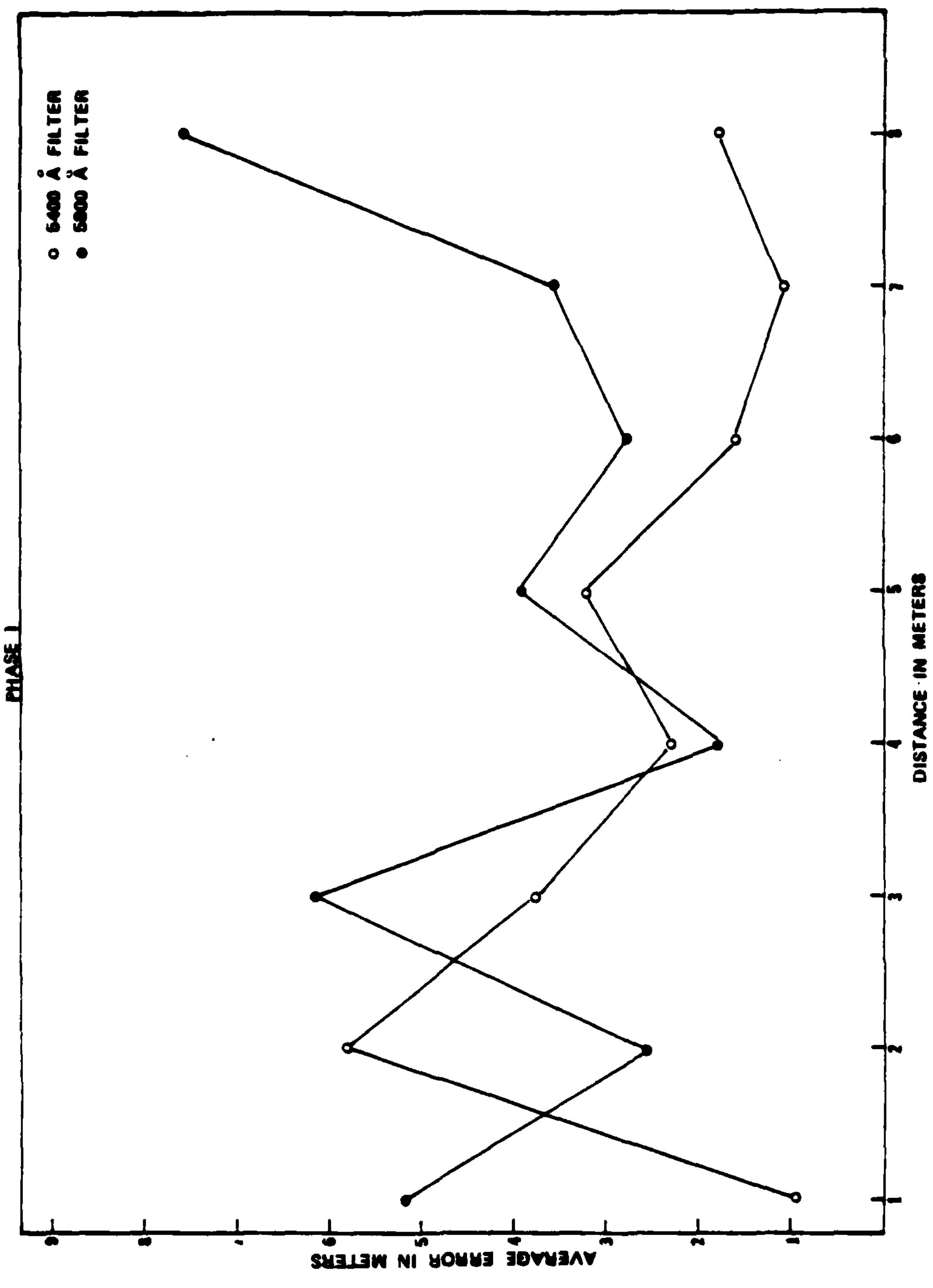

Figure 4 - Phase I - 5400 Å Filter, 5800 Å Filter

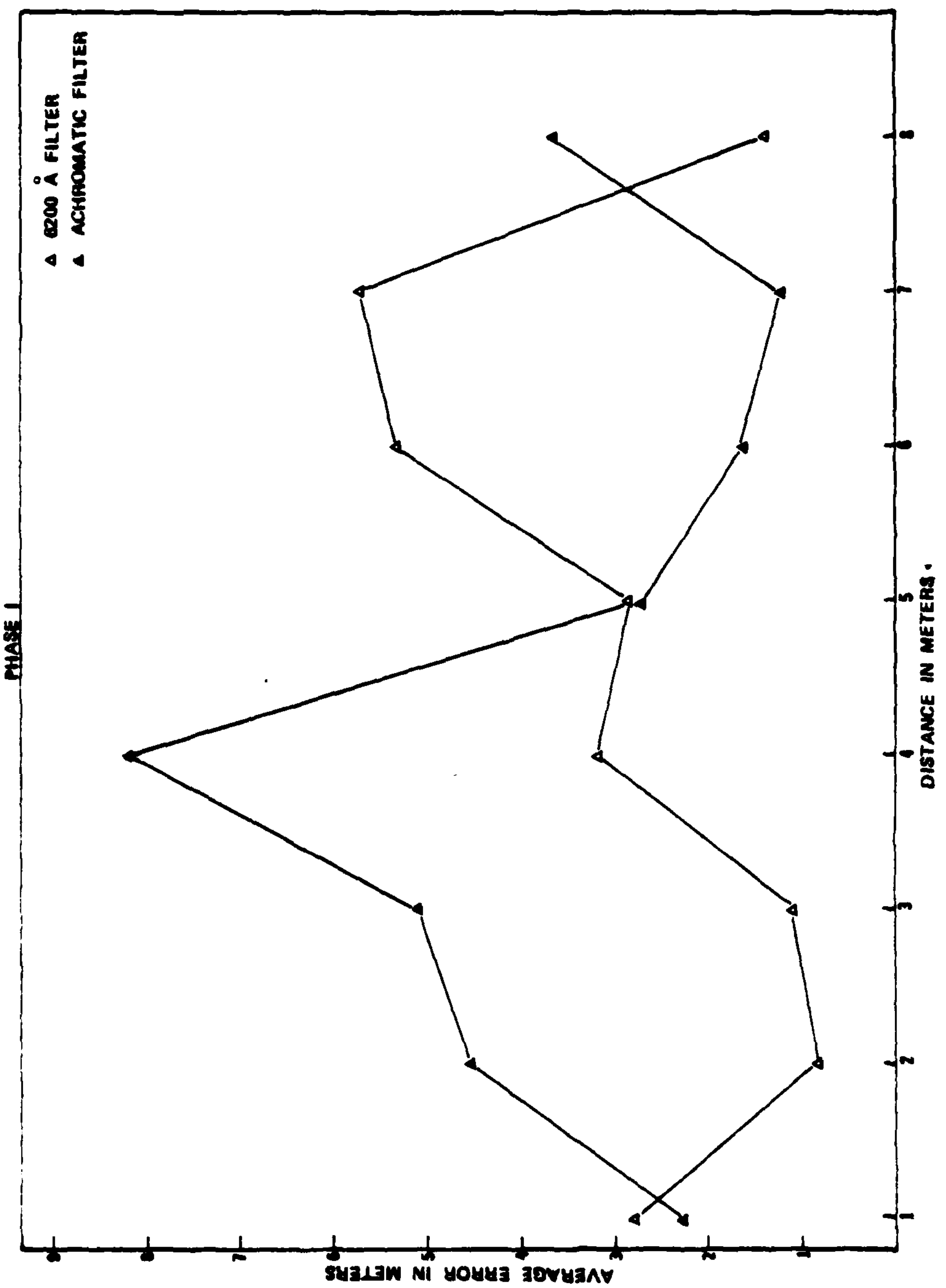

Figure 5 - Phase I - 6200 Å Filter, Achromatic Filter

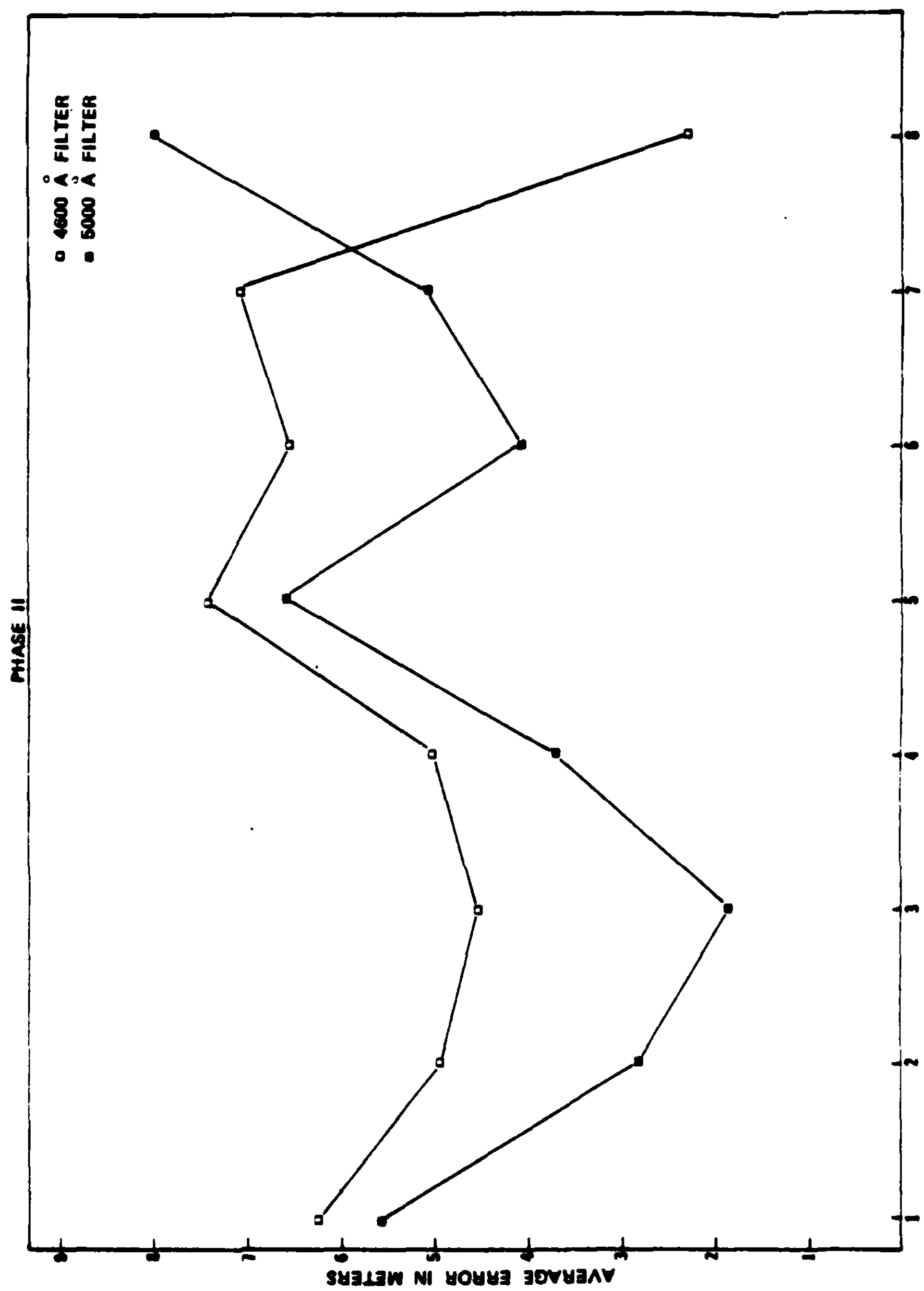

Figure 6 - Phase II - 4600 Å Filter, 5000 Å Filter

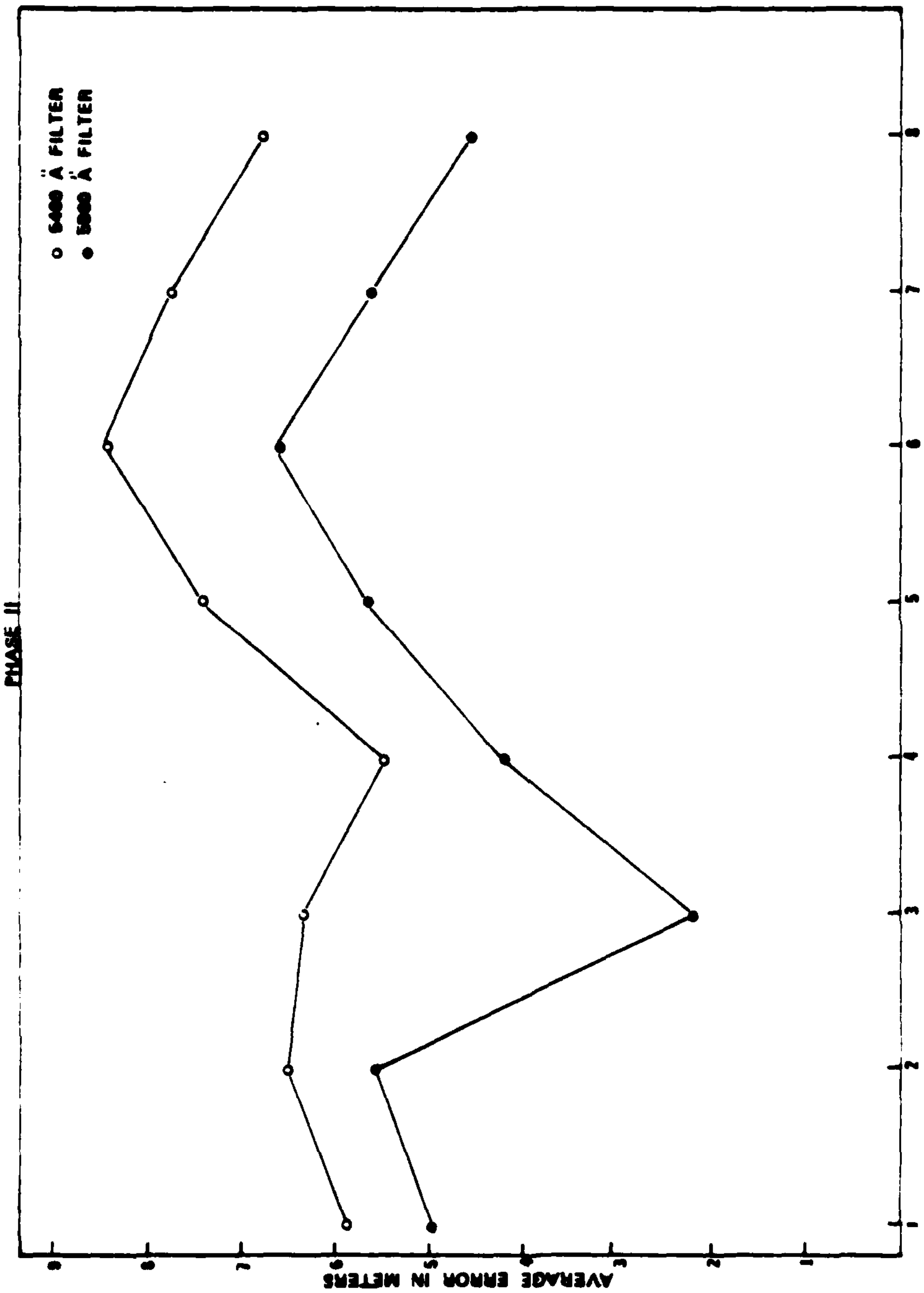

Figure 7 - Phase II - 5400 Å Filter, 5800 Å Filter

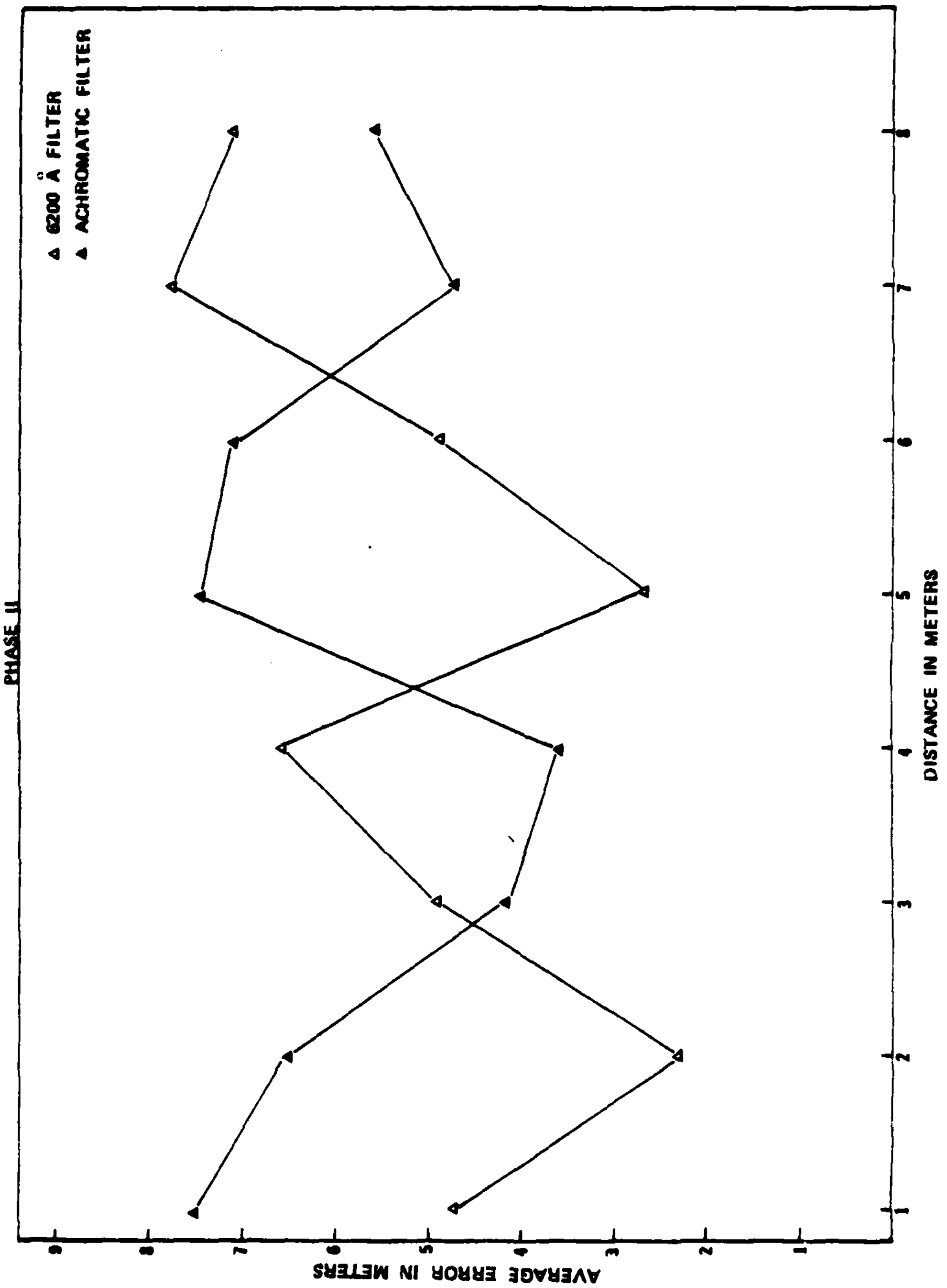

Figure 8 - Phase II - 6200 Å Filter, Achromatic Filter

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